PIONEER TECHNOLOGY INNOVATION

Flight Control Design for an Unmanned Rotorcraft Program with a Rapid Development Schedule

Jason D. Colbourne, Mark B. Tischler

Rotorcraft unmanned air vehicle (RUAV) programs are generally developed with small budgets and in time frames that are measured in months rather than in years. Unlike piloted vehicles, unmanned air vehicle (UAV) programs do not have the luxury of long design cycles with multiple iterations. The Northrop Grumman/Ryan Aeronautical Center-led program successfully developed a prototype RUAV (fig. 1) to bid on the U.S. Navy's VTOL (vertical takeoff and landing) Tactical UAV (VTUAV) program. With no remote piloted reversion mode, with no envelope expansion, and with only 4 months to design and develop the flight control systems (FCS), the prototype vehicle successfully flew an 18-minute mission for its first autonomous flight. To complete this program, design tools and methods that develop fast, accurate designs and simulation models were needed.

Over the past 3 years, Ames has been developing the Control and Simulation Technologies for the Autonomous Rotorcraft (COSTAR) program. The COSTAR initiative adapts design tools and methods developed for piloted aircraft to the RUAV platform. The three key design tools in COSTAR are (1) CIFER,® which facilitates system identification to produce linearized dynamics models from frequency sweeps; (2) CONDUIT,® which optimizes flight control laws to meet a given set of design criteria; and (3) RIPTIDE, which builds rapid configuration of real-time workstation-based simulations.

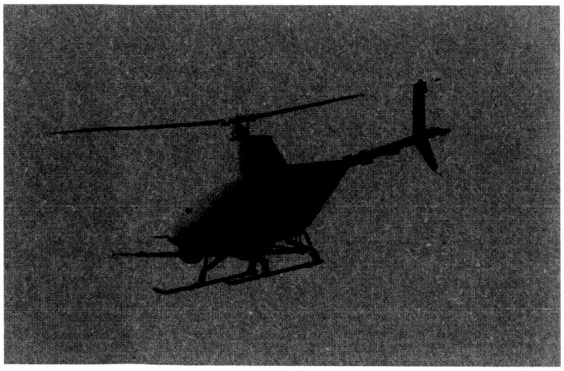

Fig. 1. Northrop Grumman's Prototype (VTUAV).

The flight control work began only 4 months prior to the first autonomous flight. Piloted flight testing was performed at the Schweizer Aircraft Corporation's facility in Big Flats, New York, to validate the basic performance of the air vehicle and to generate a flight-test database from which accurate dynamic models could be identified. Piloted frequency-sweep flight tests of the vehicle included three 100-second frequency sweeps at hover, 50, and 100 knots, and two 15-second doublets of each of the four axes.

A six-degree-of-freedom hover state-space model generated in the system identification process used the equations for a rigid body. The stability and control derivatives were tuned by CIFER so that the responses of the model matched those derived from the flight-test data. The good agreement between the flight data and the model responses and the physically reasonable stability and control derivatives, along with low Cramer-Rao percentages (the latter indicating good confidence in the identified parameters) indicated that the identified model was a valid representation of the aircraft dynamics and that it was suitable for control-law analysis and development. Identification of the hover model was completed just 2 months after the piloted frequency sweeps were performed and a month before the first autonomous flight.

A classic proportional integral derivative (PID) architecture attitude-command/attitude-hold flight control system was used to stabilize the vehicle. Eleven design parameter gains in the control laws were initially set to values based on classical design methods. CONDUIT adjusts the design parameters to optimize the performance of the control laws against 21 design specifications. The final flight-control laws were optimized in CONDUIT just 5 days before the first flight. The final design represents a good balance between stability and performance without overdriving the actuators.

The first unmanned flight of this vehicle was flown on 12 January 2000—less than 4 months after the first frequency-sweep flight data were collected for mathematical model development. This first unmanned vehicle flight consisted of an 18-minute flight over a 2-mile course. The aircraft flew a simple four-sided racetrack pattern with a ground speed of 9 knots at an altitude of 100 feet above ground level (AGL). The flight was fully autonomous from engine startup to engine shutdown including an autonomous takeoff and landing. No buildup flights were flown prior to this autonomous flight, and the vehicle had no reversion mode for ground pilot control.

Although no open-loop control doublets were performed during the tests (stability augmentation system on at all times), several moderately abrupt control transitions were observed as part of normal flight. Comparison of the simulation models with the flight data shows an excellent agreement. Figure 2 shows a pitch input that was made into the inner-loop control laws during this flight. Feeding the control input signals into the simulation model produces the response shown by the dashed curve in figure 2. The quality of the agreement shows the value of using a good simulation model in the design of RUAVs. The vehicle flight-test performance and the agreement of the flight-test data with the simulation model indicated that no further improvements to the hover low-speed FCS design were warranted.

Northrop Grumman was awarded the contract on 8 February 2000 with immediate go-ahead. First flight of an EMD vehicle is scheduled for late 2001.

Point of Contact: Jason D. Colbourne
(650) 604-6194
jcolbourne@mail.arc.nasa.gov

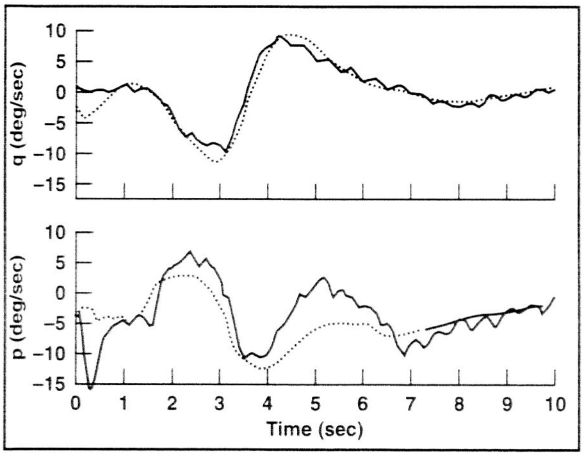

Fig. 2. Comparison of flight-test data to simulation model.

Vertical Lift Technology and NASA Revolutionary Concepts Program

Larry A. Young, John F. Madden, Khanh Q. Nguyen

Ames Research Center is a key team member on two NASA Revolutionary Concepts (REVCON) Phase I aeronautics projects, which focus on vertical lift technologies. The REVCON program is a Dryden Flight Research Center-led initiative that emphasizes the development and demonstration of high payoff aeronautics technologies that can be quickly taken from concept to flight. The REVCON projects are broken into two phases: